Home Energy Management (HEM) System

EML 4911C-Senior Design- Fall 2015

OPERATION MANUAL

Sponsor: *FEEDER*
Foundation for Engineering Education for Distributed Energy

Advisor: *Dr. Faruque*
faruque@caps.fsu.edu

Instructor: *Jerris Hooker*
Jh09c@my.fsu.edu

Team 10 Members:
Dillon Wiggins
Pablo Aguirre
Juan Jose Ospina
Ivan Remete
Michael Garcia-Rivas

Department of Electrical Engineering, Florida State University, Tallahassee, FL

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Basic Operation

Utility companies are implementing Real Time Pricing (RTP) to regulate the load demand on their systems. The HEM System was designed to take advantage of RTP to allow the customer to regulate energy cost and consumption. The HEM System is basically a computer network connecting (a) load controllers that control loads, (b) a main controller controlling the general system using an algorithm, and a (c) user interface hosted on a webserver connected via internet, all depicted in the top-level design shown in the Figure 1:

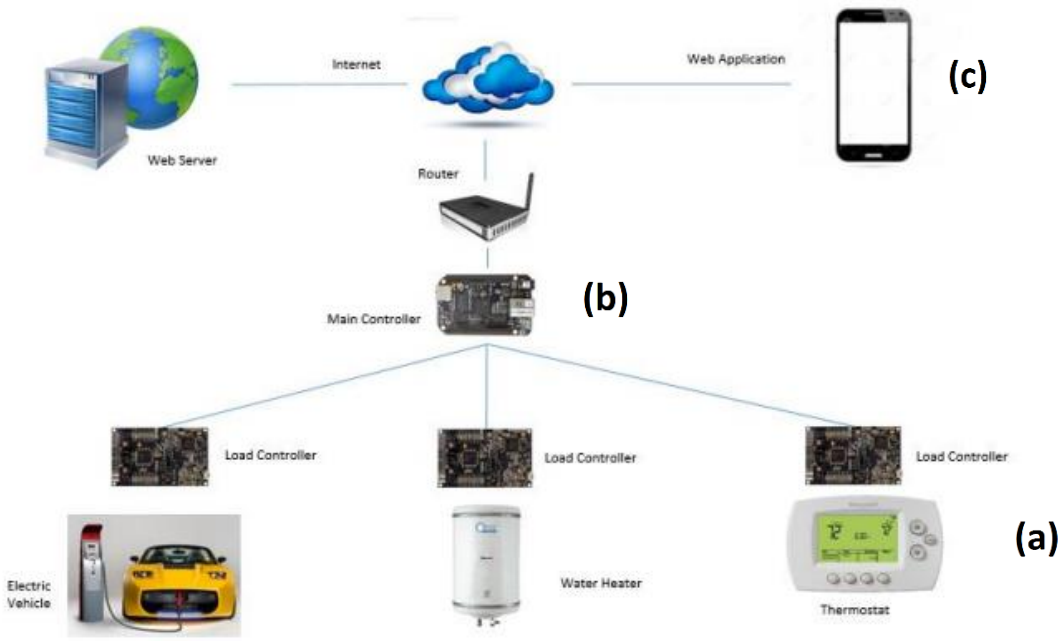

Figure 1: Overview Design of the HEM System

The load controller handles basic turning on and off each load, or, in the case of the thermostat, setting the A/C temperature, predetermined by the main controller. The main controller decides which loads should turn on/off based on (1) the algorithm's decision, or (2) the user's decision. The main controller runs an algorithm that, given certain inputs such as: the load's consumption, priority, wattage rating, as well as time of day, decides if a load should turn on/off. However, the user ultimately decides if a load should be on/off regardless of what the algorithm believes it should do. The user decides which loads to turn on/off using the website. This website hosts options that the user can customize based on each load. Some of these options include setting a temperature schedule for the A/C unit, setting a priority for each load, and setting a load's wattage rating.

How the HEM System Saves You Money?

The HEM System is designed to intelligently use various inputs acquired by the system such as, the real-time price (RTP) of energy, the consumption of loads, and the user specific settings, to control the energy consumption around your home. The HEM System use an algorithm specially designed for optimizing and reducing the consumption of your loads depending on the value of the RTP obtained from the utility company. Here's a brief look at how the system does its job:

1. The web application obtains the current RTP from the utility company, and then this RTP is fetched into the main controller through a socket connection.
2. The main controller uses the RTP to calculate the current consumption of the entire system (Σ n loads consumption).
3. Using the algorithm, the system compares the consumption to the maximum cost the user allowed to be used.
4. The system will adjust the consumption of the home by turning on/off the loads that have lower/higher priority. In order words, the system will always try to stabilize the consumption of the home depending on the settings specified by the user on the web application.
5. By using this algorithm, the HEM System automates the control of the desired loads and saves money by scheduling to run these loads when the RTP is low, thus paying less for the same amount of consumed energy.

The HEM System also offers the absolute user control of the connected loads from the web application, thus providing the user with the power to decide when to turn on/off a load and also giving the user control over the home temperature by providing a temperature schedule.

HEM System Anatomy

Main Controller

The brain behind the HEM System is the Main Controller, seen in Figure 2. The Main Controller is made of up different components that play a specific role in the Main Controllers function.

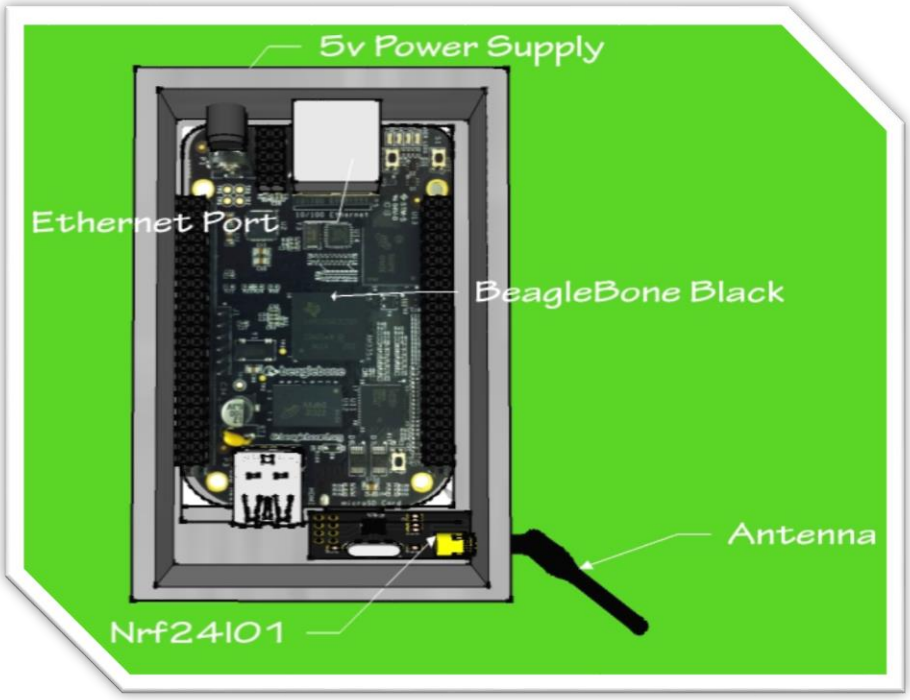

Figure 2: Main Controller

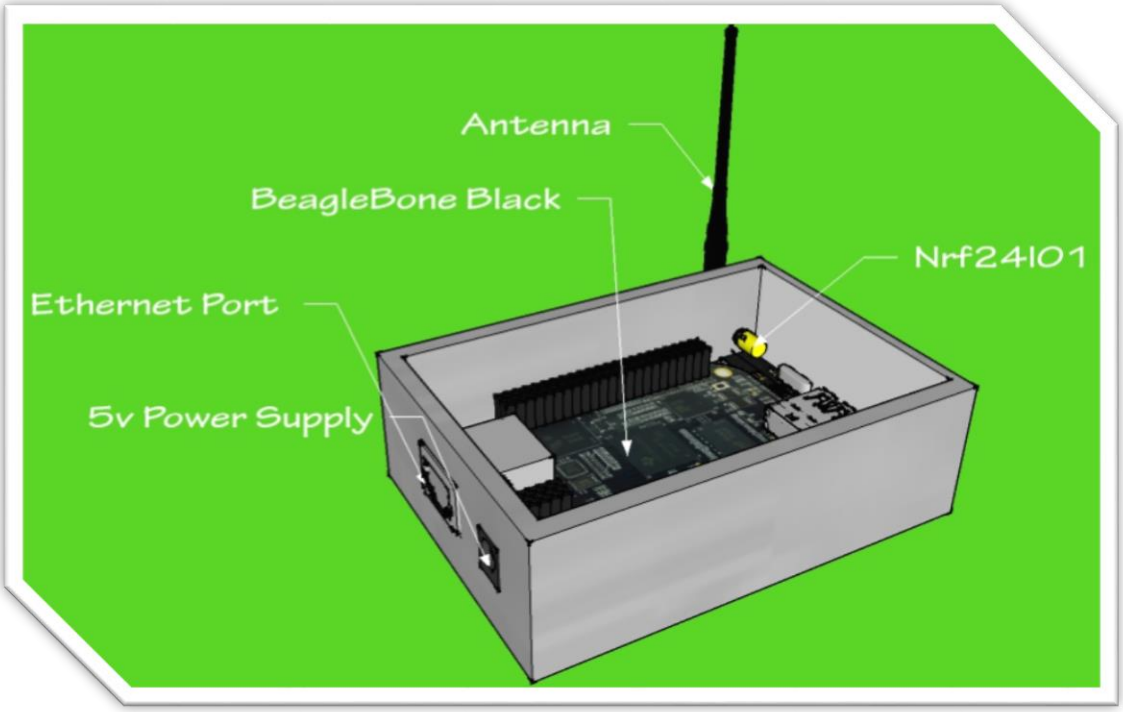

Figure 3: Main Controller Side View

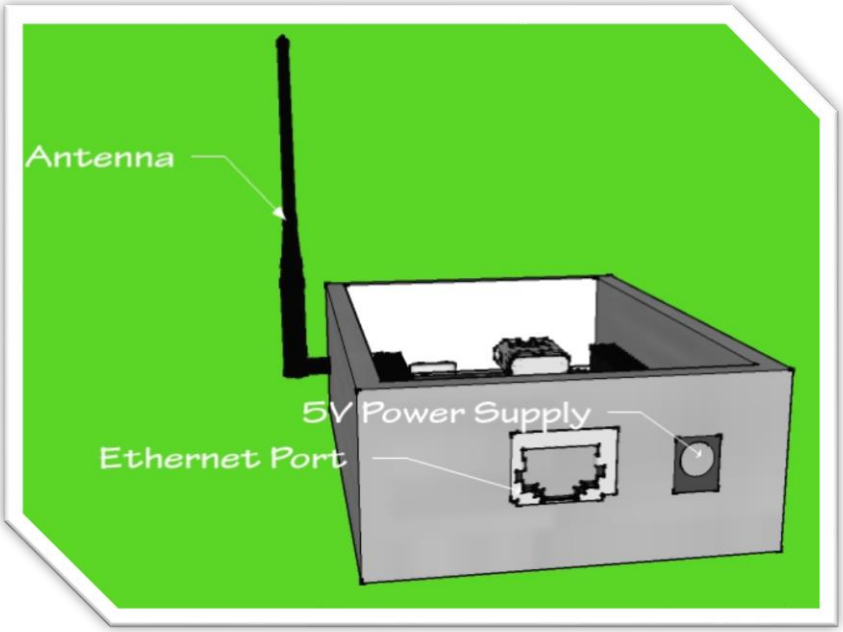

Figure 4: Main Controller Front View

Component	Description
5V Power Supply	A 5V power supply plugs into the Main Controller and provides power to all the components.
Ethernet Port	RJ45 Ethernet connector for LAN. User may use this for programming purposes as well as connecting the Main Controller to the website via internet.
BeagleBone Black	It is a lower-cost, high-expansion focused microprocessor using a low cost Sitara XAM3359AZCZ100 Cortex A8 ARM processor from Texas Instruments. It serves as the brain of the HEM System.
Nrf24l01+	Used for communication using a 2.4GHz RF transceiver, providing SPI interface with the controllers.

Load Controller

The second aspect of the HEM System is the Load Controller. The Load Controller is mainly in charge of turning the connected load on and off based on the Main Controller's command. The Load Controller can be seen in Figure 5.

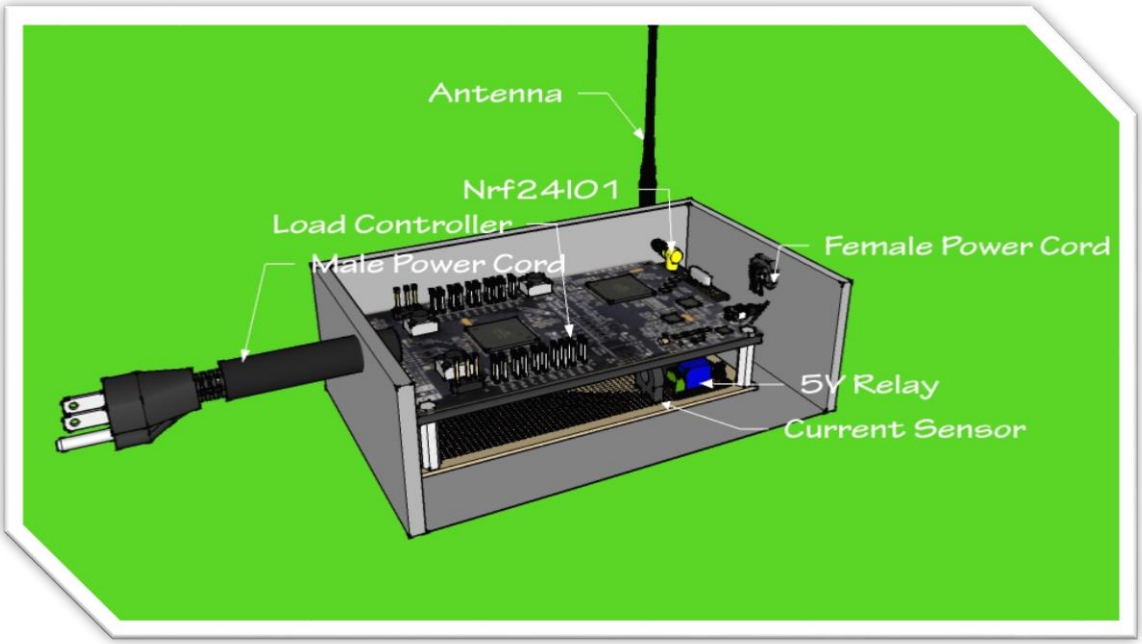

Figure 5: Load Controller

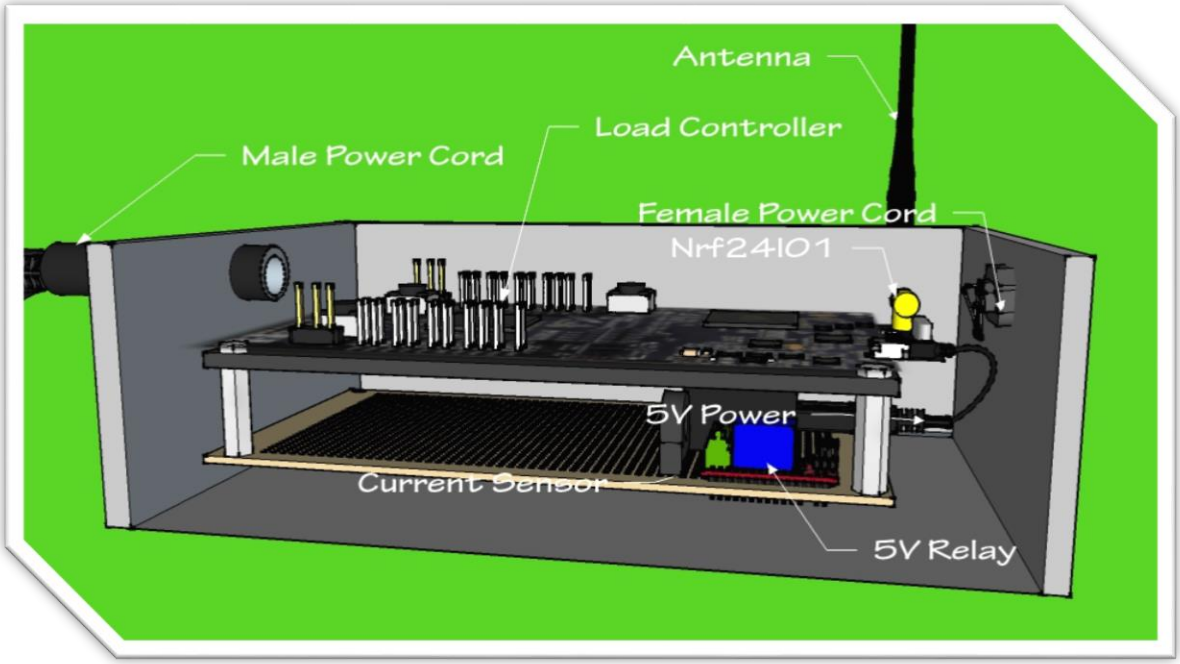

Figure 6: Load Controller Close-up

Component	Description
Male Power Cord	120V main power line for the main controller. This powers the Load Controller.
Load Controller	MSP-EXP432P401R, a mixed-signal microcontroller family from Texas Instruments.
Nrf24l01+	Used for communication using a 2.4GHz RF transceiver, providing SPI interface with the controllers.
5V Power	Black Universal AU Plug AC USB Power Charger Adapter of 1000mA.
5V Relay	5V One-Channel Relay used for turning the loads on and off.
Current Sensor	56100C Current Sensor Transformer used to detect the current of the connected load.

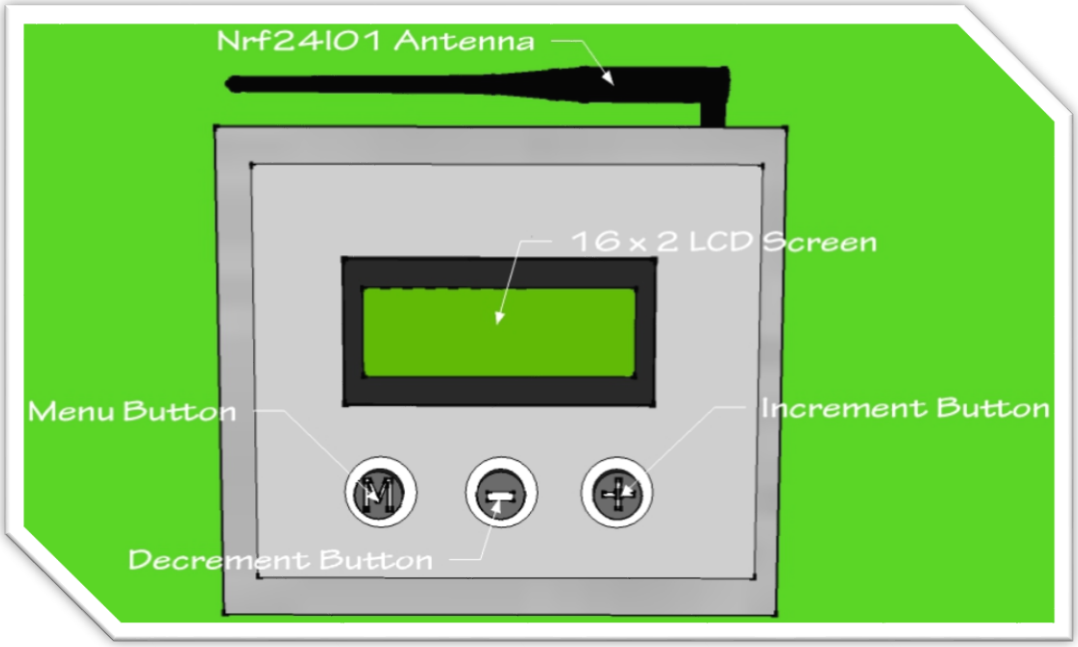

Figure 7: Thermostat

Component	Description
Nrf24l01+	Used for communication using a 2.4GHz RF transceiver, providing SPI interface with the controllers.
Menu Button	Menu Button allows you to enter the Thermostat's menu.
Decrement Button	Decrement button allows you to decrement your choice once in the Thermostat's menu.
Increment Button	Increment button allows you to increment your choice once in the Thermostat's menu.

Setup Guide

Follow these simple steps to get started with your HEM System. For additional information visit Operation Instruction section.

Figure 8: Display model home with the system installed

Installing the System

STEP 1: The Main Controller

- In a centralized location of your home, as shown in figure 8, place the main controller in an uncluttered area. **NOTE:** The main controller requires a connection via Ethernet cable. Make sure the centralized location has an Ethernet port nearby or has the router of your home nearby.
- Plug in the 5V DC power into the Main Controller and the other end into a wall outlet.
- Connect the Ethernet cable into the Ethernet port of the Main Controller and the other end into the router Ethernet connector. **NOTE:** The Main Controller's Ethernet port can be connected directly to a router.

STEP 2: The Load Controller

- Determine which loads you would like the HEM System to control.
- Once determined, disconnect the load from the wall outlet.
- Connect the Load Controllers input to the wall outlet and the output to the desired load.
- Repeat **STEP 2** until you have connected all of the Load Controllers to the desired loads which you would like the HEM System to control.

STEP 3: The Thermostat

- Replace your current thermostat with the controllable thermostat provided.

Connecting the Main Controller to the inner network (LAN)

NOTE: The LAN Network can only be accessed in your personal home. To access the website remotely please refer to Connecting the Main Controller to the outer network remotely.

STEP 1: Access your router's web interface

- Open the Network and Sharing Center in the Windows Control Panel

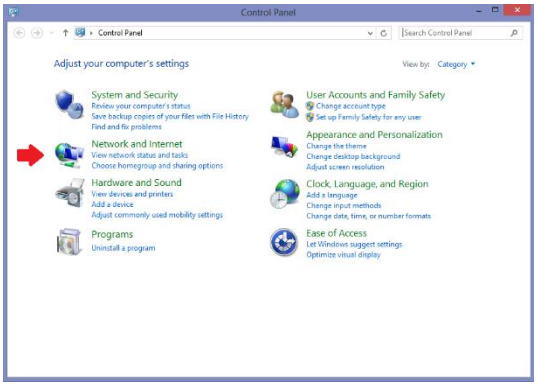

Figure 9: Control Panel

- Once opened, click on your personal Wi-Fi's name under **Connections**.

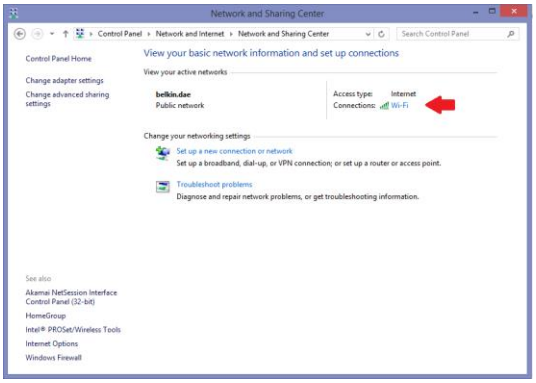

Figure 10: Network and Sharing Center

- Once opened, a **General** panel will appear. Click on the **Details** bar. The **Network Connection Details** will give you the routers IP Address under **IPv4 Default Gateway** as 192.168.X.X

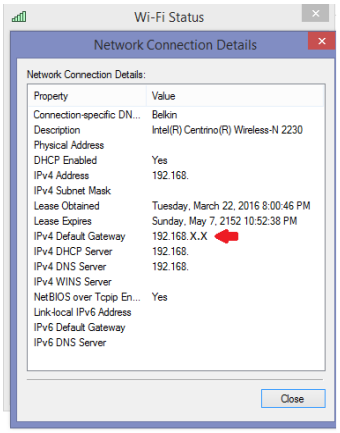

Figure 11: Wi-Fi Status

- Once the **IPv4 Default Gateway** is obtained, plug in the IP address into your web browser's address bar. You will need to log with your username and password. Once you've logged in, you can obtain the Main Controller's IP address.

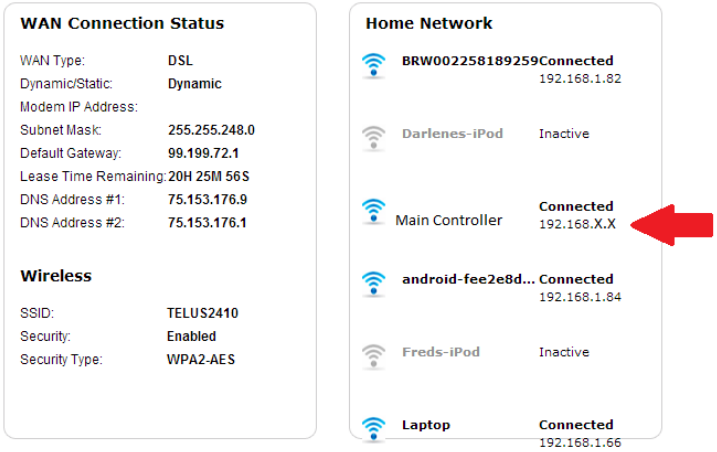

Figure 12: Wi-Fi Networks

STEP 2: Accessing the HEM System website

- Use the IP address obtained from the previous step to access the HEM System website locally by imputing the IP address into the web browser. **NOTE:** For instructions on using the HEM System website refer to the **System Operation** section.

Type on URL: 192.168.x.x (IP of your Main Controller)

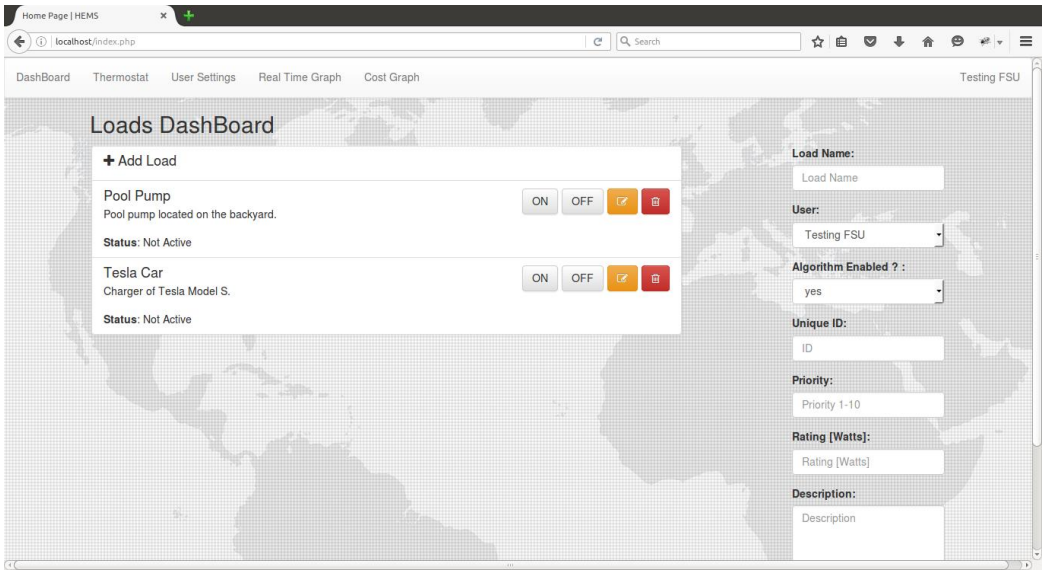

Figure 13: HEM Website Interface

Connecting the Main Controller to the outer network remotely

For accessing the HEM system remotely, you must first connect the Main Controller to your own LAN following the instructions explained on **Connecting the Main Controller to the inner network (LAN).** After your system is working on your own LAN, you must **port forward** the private IP of the Main Controller following the next steps:

NOTE: Before attempting these steps, please make sure the LAN connection is working correctly.

Port Forwarding

STEP 1: Access your router by typing the IP on the address bar of your web browser. This will open your router's configuration page. Most routers have 192.168.0.1, but that's not always the case, so please check the router's manual.

STEP 2: Log in to your router's configuration page by typing your username and password. This information should be available on your router's user manual.

STEP 3: Find the Port Forwarding section. On most routers it can be found on Advanced Settings or Applications.

STEP 4: Create a custom entry. In this part, the user should add the internal IP to the list of Forwarding and list the port 4000 (if you want to use a specific port for communication). For the service type use TCP option.

STEP 5: Click on Add and Enabled, then save current settings. You might need to restart your router for the changes to take effect.

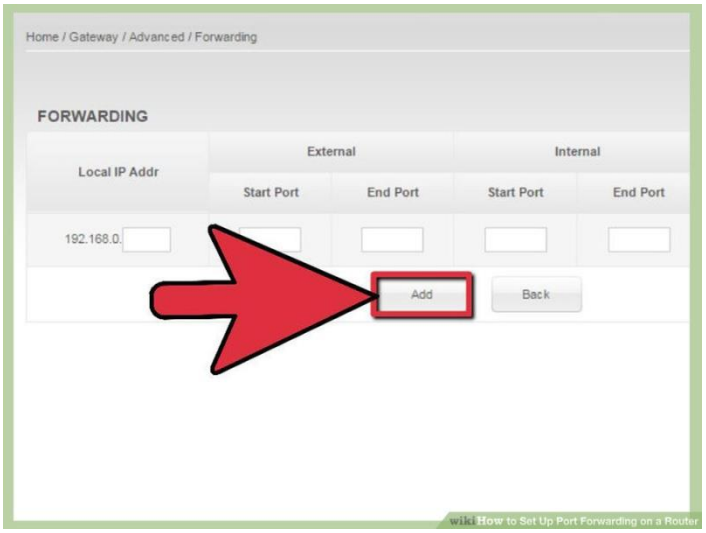

Figure 14: Port forwarding

This connection works correctly until the Dynamic Public IP of the home user changes. This change can't be predicted since it could happen at any time, and only the ISP has full control of this action. So, in order to solve this issue, the design must introduce the use of another technology called Dynamic DNS.

Dynamic DNS (DDNS) is, in essence, a method for the automatic update of the name server in the DNS with the active DDNS configuration present on the hostnames or host addresses. In other words, this is the method in charge of assigning a logical name, like "logical.ns01.info", to the public dynamic IP assigned to the home user by the ISP.

You can find free and paid services available; some examples are www.noip.com or www.dyn.com.

Warning: The HEM System group doesn't encourage the use of this method for the system, since giving remote access to the entire system could be extremely dangerous due to security flaws on the network. Exposing your inner network to remote access should be done taking serious security considerations.

System Operation

Log in/out to/from the Web Application

Log in to the web application (create a profile if it's your first use – Click on create a new profile and follow the instructions).

Enter your registered email address and password to access the personal system.

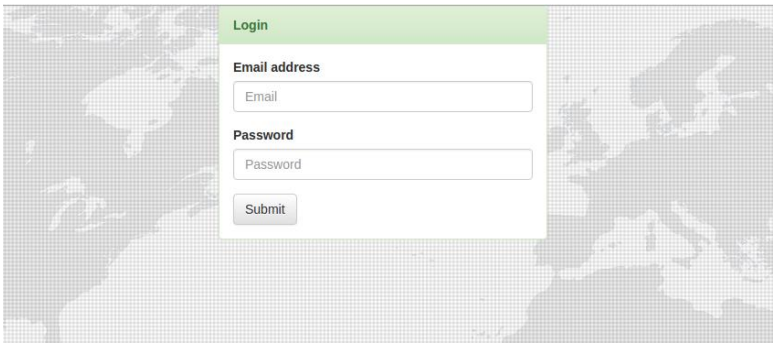

Figure 15: Login Interface

To log out from the website go to upper right side of the page, click the name of the current user and press **Log Out**.

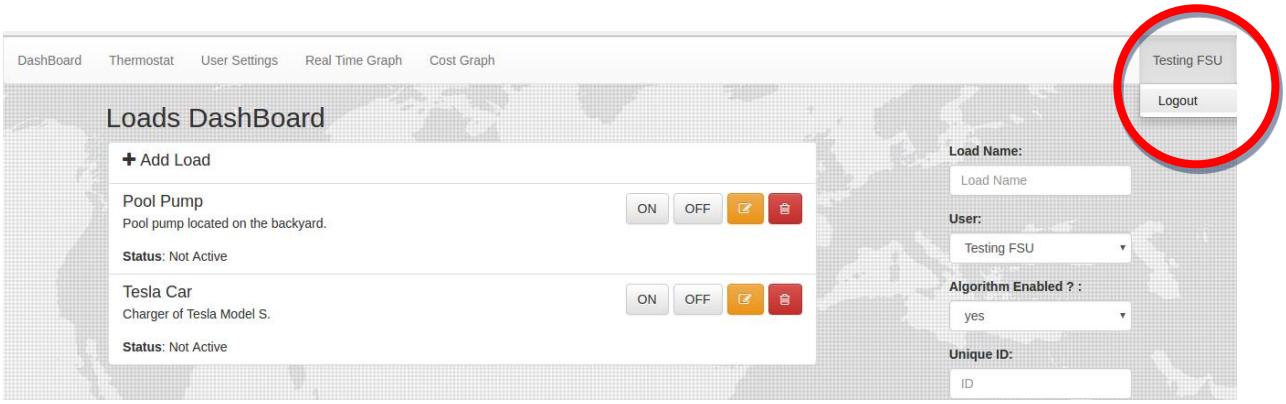

Figure 16: Logout from Web Application

Adding Loads

To add loads to the system, disconnect the load you wish to add to the system and connect it to a Load Controller box. Write down the ID located on the top of the Load Controller box, since it will be used later when added to the web application.

- Log in to the web application (create a profile if it's your first use – Click on create a new profile and follow the instructions).
- Click on **Load DashBoard** to access the dashboard where all your registered loads are displayed.
- Click on **+Add Load** and fill out the information located at the right side of the page.

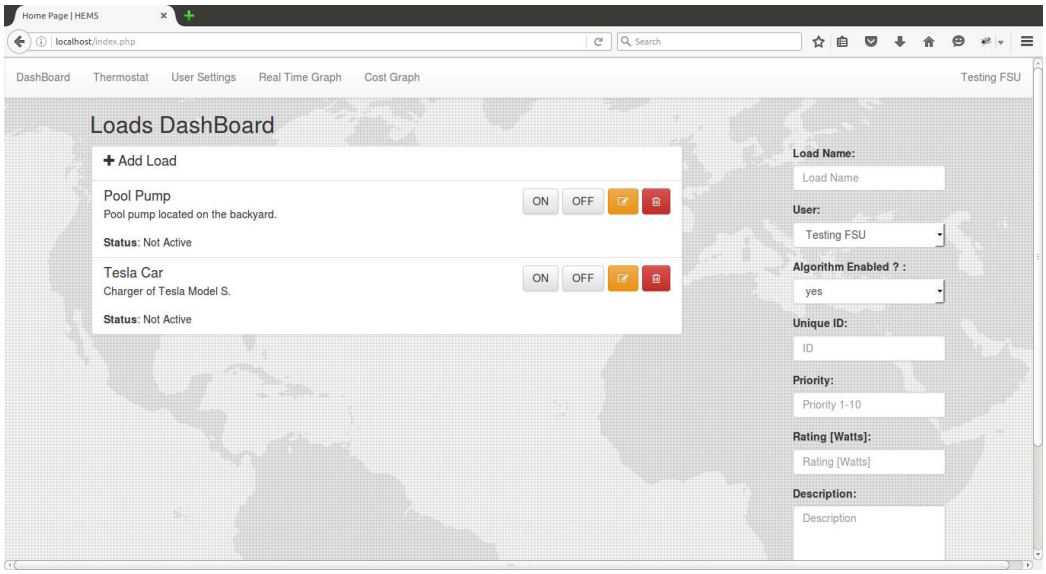

Figure 17: Load Dashboard

1. **Load name:** Fill out with the name you want to give to the load.
2. **User:** Select the administrative user of the load.
3. **Algorithm Enabled? :** Select yes if you want the system to use the algorithm to turn on/off the load depending on the parameters specified: RTP, consumption, priority, etc…
4. **Unique ID:** Fill out with the unique ID located on the front of the Load Controller box. It's important to use the correct ID number.
5. **Priority:** Fill out with a number from 1 to 10. 1 is the lowest priority, 10 is the highest priority. Lower priority loads turn off first when using the algorithm response.
6. **Rating:** Fill out with the specific power rating of the load you are connection to the Load Controller box. This information is necessary for a correct consumption calculation and algorithm response.
7. **Description:** Fill out with a brief description of load you are connecting to the system. (Optional)
8. **Save/Update Button:** Saves or updates the information of the specific load.
9. **Image Dropzone:** An image can be assigned to any load. Drag and drop the preferred image to the dropzone that appears below the Save/Update button.

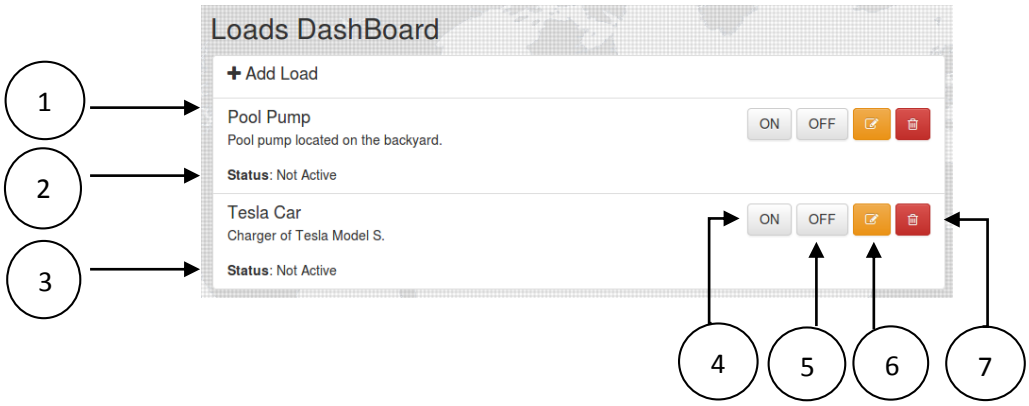

Figure 18: Details and Buttons

1. **Load name**
2. **Load description**
3. **Status:** Active/Not Active – tells the status of the load.
    a. **Active:** Load Controller box relay is ON (letting possible current to pass) and the load is drawing current. Load Controller is ON and Load is ON.
    b. **Not Active:** Load Controller box relay could be ON (letting possible current to pass) but the load is not drawing current. Load Controller is ON and Load is OFF.
4. **ON Button:** Press this button to turn ON the specific load.
5. **OFF Button:** Press this button to turn OFF the specific load.
6. **Edit Button:** Press this button to edit the information of the specific load.
7. **Delete Button:** Press to delete the specific load from the system.

Editing Loads

Press the **Edit** button to edit the information of the selected load. When the **Edit** button is pressed, the right side text boxes, containing the information of the selected load, are populated.

When the **Edit** button is pressed, the image of the selected load will appear at the bottom of the load's list. This image is the one uploaded by the user using the Dropzone option.

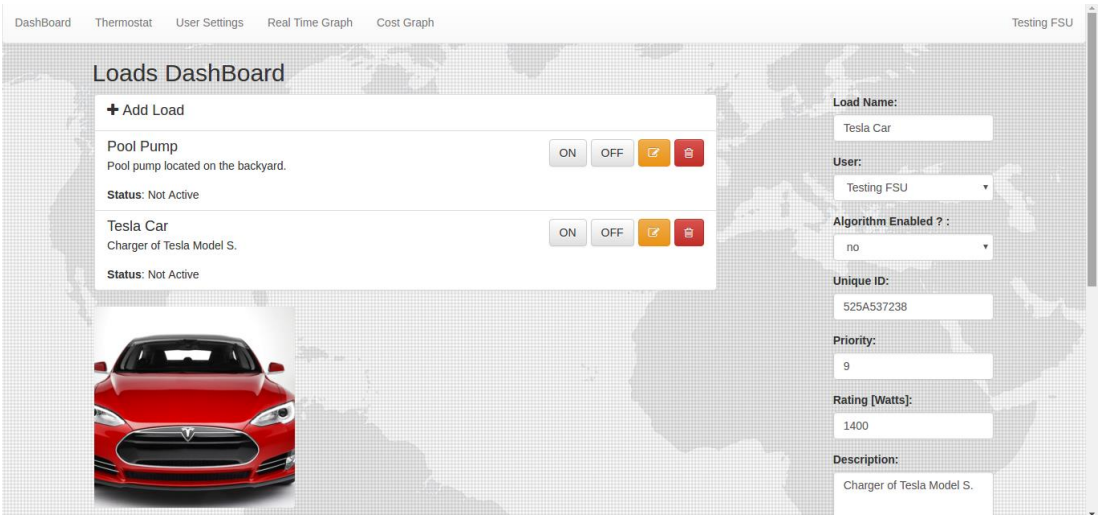

Figure 19: Loads Dashboard Editing Load with Images

Using the Thermostat Controller

Access the Thermostat section of the web application by clicking on **Thermostat.**

- **Thermostat Controller Interface**

  - To change the temperature, click on the **Up/Down** arrow.
  - **Set** indicates at which temperature the system has been set.
  - **Current** indicates the current temperature of the home.

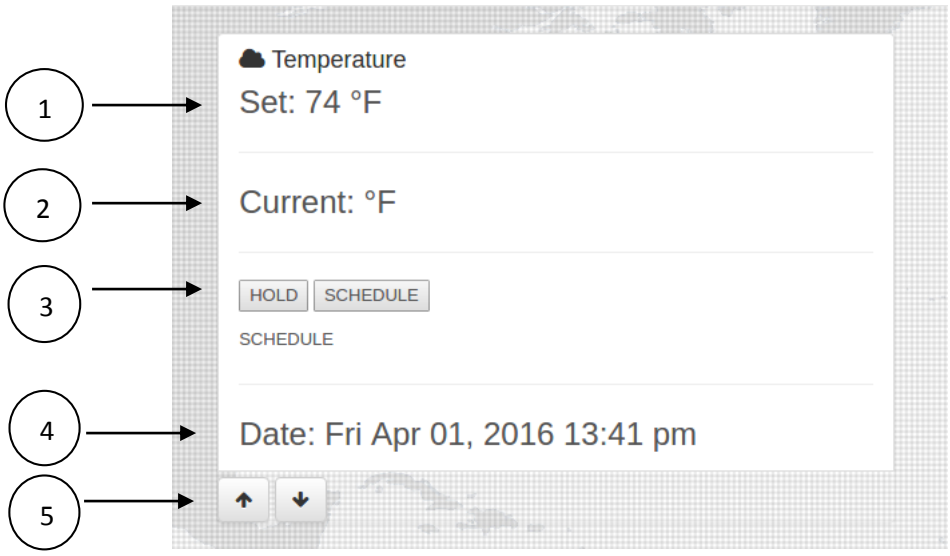

Figure 20: Thermostat Controller Interface

1. **Set:** Temperature set on the system.
2. **Current:** Current temperature of the home**.**
3. **Hold/Schedule:** Select the option that defines how the system will work.
    a. **Hold:** The system will maintain the **Set** temperature until changed to **Schedule**.
    b. **Schedule:** The system will run the schedule given by the user. For details in how to change the **Schedule** settings go to **Using the Thermostat Schedule**.
4. **Date:** Shows the current date and time.
5. **Up/Down arrows:** Press the Up/Down arrows to change the **Set** temperature (desired temperature).

Using the Thermostat Schedule

The Schedule section offers the possibility of having up to 10 different scheduled temperatures at different times.

Setting up the schedule: to change a specific scheduled temperature, click the **Edit** button located at the right of the selected temperature. This will populate **the text boxes** located at the right side of the page. Change the settings to your preference and click **Update**. See Figure 21.

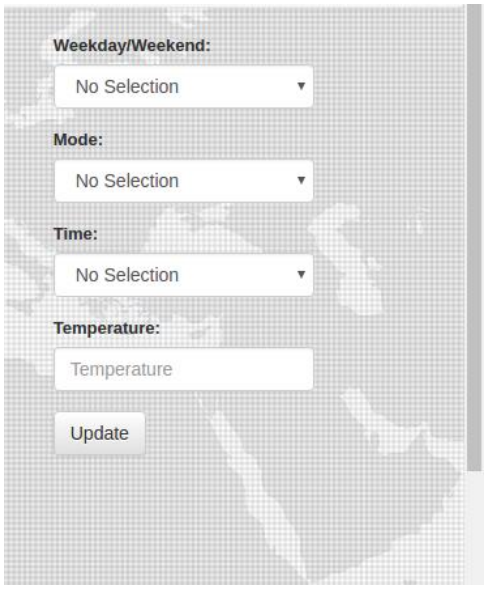

Figure 21: Edit Text Boxes

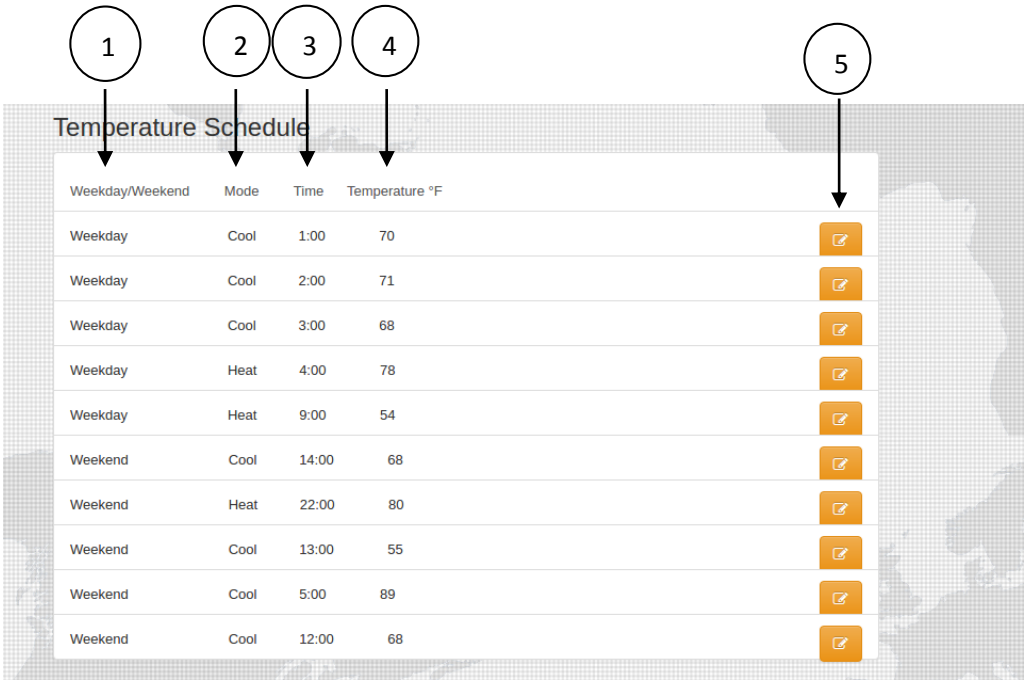

Figure 22: Temperature Schedule

1. **Weekday/Weekend**
    a. **Weekday:** Monday – Friday
    b. **Weekend:** Saturday – Sunday
2. **Mode**
    a. **Cool:** Cooling mode.
    b. **Heat:** Heating mode.
3. **Time:** Select the Time for the scheduled temperature (1-24).
4. **Temperature:** Select the desired temperature for the selected time.
5. **Edit Button:** Press to change the settings for the selected temperature.

Thermostat Hardware Control:

Figure 23: Thermostat Buttons

M: Press to enter Menu Mode and to cycle through the settings

- : Press to decrement Desired Temperature or decrement setting in Menu Mode

+ : Press to increment Desired Temperature or increment setting in Menu Mode

Thermostat Display:

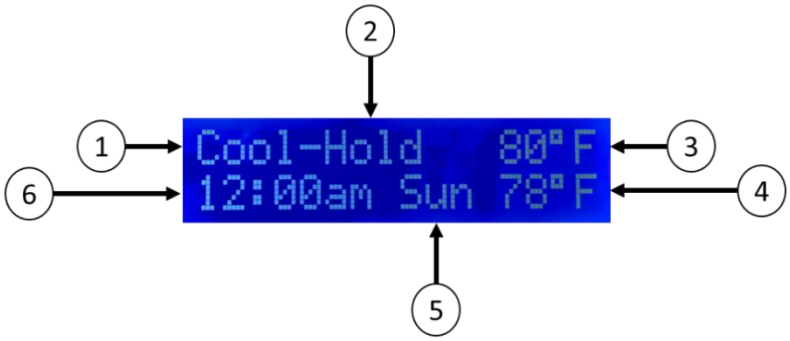

Figure 24: Thermostat Display 1

Figure 25: Thermostat Display 2

1. Cool or Heat
2. Hold or Schedule
    a. When Hold is selected, the thermostat will not utilize the schedule and the desired temperature can only be changed via the “+” and “-” buttons.
    b. When schedule is selected, the thermostat will execute the schedule that is set on the website. The temperature can be changed via the “+” and “-” buttons but will resume the schedule at the next set time.
3. Desired Temperature: This is the temperature that is desired by the user.
4. Actual Temperature: This is the ambient temperature as detected by the thermostat.
5. Day of the Week: Will be displayed using the first three letters of the day.
6. Time: Displayed using hh:mm format and utilizing am or pm.

Menu Mode:

In order to enter menu mode first press the “M” button. Once the button is pressed, the current selection will blink at approximately 1 Hz. In order to change the current selection utilize the “+” or “-” button. To move to the next setting press the “M” button again. When the current selection is the “Day of the Week” and the “M” button is pressed, Menu Mode is exited.

User Settings

Enter Maximum Monthly Price: Enter on the text box the value in $ (dollars) of the maximum price you want to pay per month and click **Send**. The system will store the specified value and perform its calculations based on it.

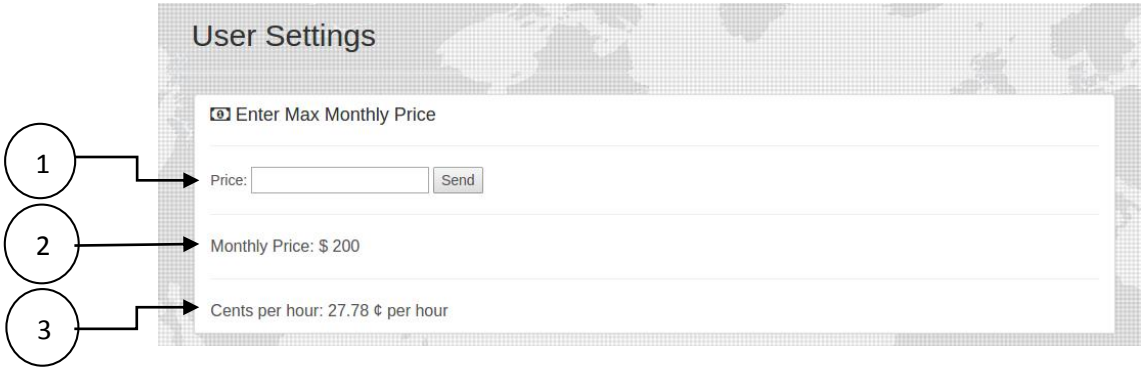

Figure 26: User Settings

1. **Price Text Box:** Enter the desired maximum price for the system.
2. **Maximum Monthly Price:** Display of the maximum monthly price entered.
3. **Maximum Price per Hour:** $\frac{\left(\frac{\text{Monthly price}}{30\text{ days}}\right)}{24\text{ hours}}$

Real-Time Price Graph

The web application offers users the opportunity to see the real-time price of electricity given by the utility company throughout the day (using a 24-hour span).

Figure 27: Real-Time Price Graph

Consumption Graph

The web application offers users the opportunity to see the historical consumption of electricity throughout the day (using a 24-hour span).

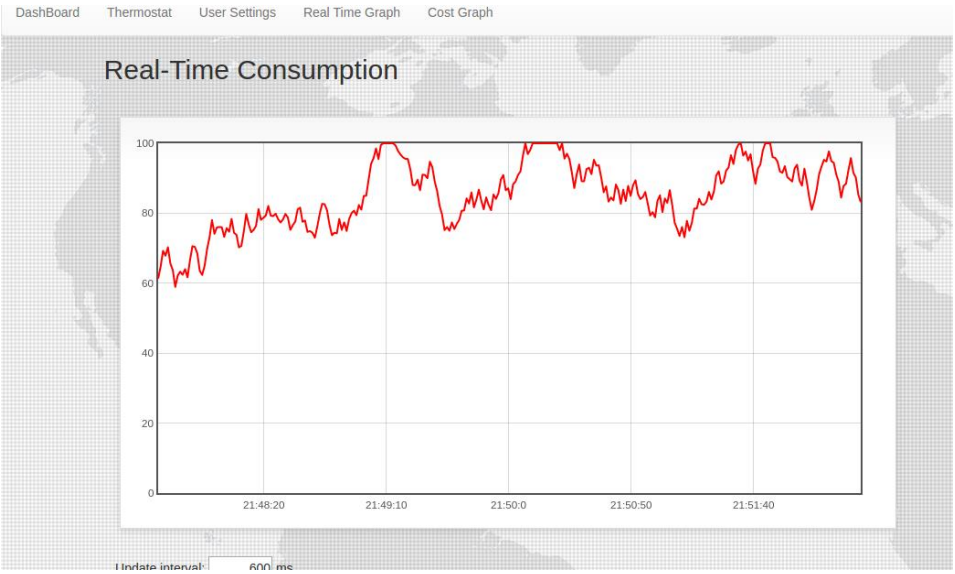

Figure 28: Consumption Graph

Important Safety Information

This appliance can be used by adults only and persons with reduced physical, sensory or mental capabilities or lack of experience and knowledge if they have been given supervision or instructions concerning the use of the system in a safe way and understand the hazards involved. Children shall not play with the system. Cleaning and user maintains shall not be made without unplugging the component.

Read all safety and operating instructions before operating the system.

- Retain the safety and operating instructions for future reference.
- Heed all warnings in the owner's manual.
- Follow all operating and use instructions.
- Do not use a Load Controller or thermostat with a damaged cord or plug. If the cord or plug is damaged, it must be serviced by the manufacturer or similarly qualified persons.
- Never handle the Load Controller or thermostat with wet hands.
- Please ensure voltage rating for Load Controller matches standard outlet voltage.
- Load controllers are for indoor use only.
- Use Load Controller only in dry environments.
- Do not spray or pour liquids on Load/Main Controller or thermostat.

CAUTION: DO NOT REMOVE THE COVER(S) OF LOAD/MAIN CONTROLLERS OR THERMOSTAT.

Troubleshooting & FAQ

How should I determine a load's priority number?

A priority 1 should describe a load that has the least amount of importance to your home because these will be the loads the algorithm decides to turn off first. For example, a general accent lighting could be a priority 1 while a more important accent lighting could be a priority 2. Ultimately, the user decides what they find more important.

Why is the load not responding?

1. Check to see if load is on the website. If not, refer to the **Adding Loads** section for more information.
2. Make sure all connections are made and the power is supplied to the Load Controllers.
3. If the load is not being manipulated by the algorithm when it should be, it might not be *algorithm enabled* which can be defined for each load on the website.
4. Some loads might not have the correct priority and therefore do not turn off/on when reaching.

How do I tell a load's wattage rating?

Usually most appliances have their wattage rating displayed in their manual. If not, a quick online search could find the wattage rating of most consumer appliances.

My thermostat is acting weird, what should I do?

Try unplugging it and plugging it back in. This will reset the thermostat module to its default settings. Time, temperature, schedule mode, and heat/cool will bet set to 12:00AM, 80 degrees, hold, and cool, respectively. From there you can use the menu button to reset these values with the correct values.

My router is not detecting the main controller, what should I do?

Try disconnecting the Main Controller from the router and unplug it from the wall. Wait 30 seconds and connect the cable to the router.

Networking: Port Forwarding Issues

See **Connect the Main Controller to the outer network remotely** under **Setup Guide** and if you need more information go to the following website http://www.wikihow.com/Set-Up-Port-Forwarding-on-a-Router

For further questions, contact customer support at HEMSystemFSU@gmail.com

Appendix

Table of Figures